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CLOUDS

Mark K. Seager

August 1979

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Final Report

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Air Force Weapons Laboratory
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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The following report is an in-depth Users Manual for the ANSI FORTRAN computer program CLOUDS. CLOUDS is designed in two major blocks: cloud field generation and cloud-free line-of-sight (CFLOS) calculation. The cloud field generation block models observed cloud fields using rotated truncated ~~elipsoids~~ and rotated ~~eliptical~~ cylinders. The user can specify an overall (total) cloud cover or cloud cover by base height, dimensions of the clouds to be used, and fraction of clouds to be cylinders. When the cloud field has been completed, two types of
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20. ABSTRACT (Cont'd)

plots (two-dimensional printer plots and three-dimensional META Plots) can be generated in order to view the modeled cloud field. The CFLOS calculation block generates trajectory data using either direct intercept or a chase model. Alternately, a trajectory with one defender and one to four aggressors generated by the Trajectory Analysis Program (TAP) can be used. Instantaneous CFLOS and CFLOS over discrete time intervals are calculated between the defender and each aggressor. The trajectories are rotated some user specified number of times within the stationary cloud field and the CFLOS data are recalculated.

PREFACE

The author thanks the following Air Force Weapons Laboratory (AFWL) employees: Mr. Ronald J. Nelson and Major Neil P. Philliber for the conception and initiation of the CLOUDS computer program; Major Gary J. Thompson for the many consultations; and Captain Mike Hanna, Mr. Harry Murphy, and Mr. John Burgio for their programming suggestions and debugging insight.

CONTENTS

CONTENTS (Cont'd)

SECTION I

INTRODUCTION

A. MOTIVATION

Since the advent of optical and infrared detection and tracking devices, the problem of static and dynamic cloud-free line-of-sight (CFLOS) has become increasingly important. In 1975, Nelson and Wetherbe (Ref. 1) did a first approximation study. They concluded that "it would seem that the probability of having a cloud-free line-of-sight, either instantaneous or for as short a period as one second, will be low even in fair weather conditions". They also went on to remark the following:

"To solve a dynamic CFLOS problem one requires a detailed knowledge of the initial positions and subsequent velocities of the two points between which the line-of-sight is to be assessed, detailed knowledge of the boundary conditions related to the space/time dimensions of the problem, and detailed knowledge of the cloud field characteristics, including the 3-dimensional geometry and spatial distribution of the individual cloud elements. The dynamics of a problem might be definable through a knowledge of the operational characteristics of the aircraft involved. The boundary conditions and time increments to be used in the line-of-sight assessment might stem from the characteristics of the electro-optical system."

Thus, it became apparent to Nelson that a second level of approximation was needed. This led to the development of CLOUDS.

B. THE PRESENT MODEL

The second level of approximation (or sophistication) came into the problem with the development of CLOUDS. This program uses a three-dimensional cloud field consisting of rotated elliptical cylinders and rotated truncated ellipsoids. The trajectory generation capability in CLOUDS consists of the standard direct intercept and chase models (Section II.B.1, II.B.2), but virtually any scenario can be input through the use of the Trajectory Analysis Program (TAP). The statistical calculations performed in CLOUDS have their

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1. Nelson, R. J. and Wetherbe, M. B. Some Aspects of Estimating the Probability of Cloud-Free Lines-of-Sight in Dynamic Situations, AFCTAC TN 76-2, U. S. Air Force Environmental Technical Application Center, Scott Air Force Base, IL., March 1976.

data base in CFLOS for a given time between one point on the defender's trajectory and one point on one of the aggressor's trajectories. Thus, CLOUDS offers extensive scenario generation flexibility through a three-dimensional solution to the CFLOS problem.

This report is designed to be an in-depth User's Manual for the CLOUDS program. Examples of input decks and the resulting output are described (Section III and IV). The overall program structure is discussed in Section III and crucial mathematcal developments described in Appendices A, B, and C. The CLOUDS computer program is written entirely in American National Standards Institute (ANSI) FORTRAN (Ref. 2). When compiled and run on the AFWL CDC-CYBER 176 computer, CLOUDS requires 53,188 words (147,704 Octal) of core for instructions and storage. Running time varies greatly with the type of problem. Typically, for two base heights (40 percent cloud cover at each), the running time is under 100 (144 Octal) seconds.

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2. ANSI FORTRAN, X3-9, American National Standards Institute, New York, 1966.

SECTION II
COMPUTATIONAL TECHNIQUE

The CLOUDS computer program was designed using modular construction. Modular construction of a computer code offers many advantages. Among them are: (1) it makes debugging much easier, (2) it permits dropping of a normally run portion of the code with only minor changes to the program structure, and (3) it is much easier for the user to become familiar with the computer code.

The CLOUDS computer program consists of two major blocks. The first block, designated as the CLOUD FIELD GENERATION BLOCK, reads the input data, determines the placement of the clouds via the input data, and constructs the cloud field. If desired, the cloud field is plotted. The second block, designated as the SCENARIO GENERATION AND CFLOS CALCULATION BLOCK, determines from the input data which method is to be used in scenario generation and performs CFLOS and DCFLOS (CFLOS over some finite time interval) calculations. At this point the trajectories of two vehicles can be plotted. The final step in this block, and in the program, is to output all the relevant data.

The following is a detailed description of each of the modules except the input and output modules which are discussed with examples in Sections III and IV, respectively.

A. CLOUD FIELD GENERATION BLOCK

1. Cloud Placement

The CLOUDS program can generate two types of clouds: rotated elliptical cylinders or rotated truncated ellipsoids (only the upper half is used). Thus, the base of either type of cloud is an ellipse. The intersection between the semimajor and semiminor axis of this ellipse is known as the cloud seed. Cloud placement refers to the placement of a cloud's seed in the ground-based observer's reference frame. When clouds are placed, their seeds must remain within a hemisphere centered at the ground-based observer's origin. This hemisphere is known as the sphere of cloud placement. The actual placement of seeds may be performed in one of two ways: overall placement or placement by base height. A description of how to activate either of these methods is given in Section III.B.2. Here we will concentrate on the computational procedure for each.

a. Overall (Total) Placement

Using the user inputted base heights (minimum of 1) and total cloud cover, CLOUDS "randomly" picks one of the base heights as the Z coordinate for the seed. Next, the X and Y coordinates of the seed are randomly picked so that the seed remains within the hemisphere of the cloud placement. After the seed is placed, the cloud is constructed from the possible X lengths, Y widths, and Z thickness supplied by the user. This procedure is repeated until the user specified total cloud cover is reached.

b. Placement by Base Height

Given the base heights (minimum of 1) and the percent of desired cloud cover at each base height, CLOUDS starts placing seeds in the first (bottom) base height. Thus, the Z coordinate of the seed is "fixed". The X and Y coordinates of the seed are found in the same manner as in the total placement method. After the specified cloud cover is reached in this base height, seeds are then placed in the next base height, and so on. When each of the base heights have the specified cloud cover, the seed placement terminates.

NOTE: If one wishes to have just one base height, the two methods of placement are mathematically equivalent. But for efficiency, the total placement method should be used.

2. Computing the Sky Cover Between Two Base Heights

Sky cover (the fraction of sky covered by clouds as seen by a ground-based observer) is always computed between an upper base height (HT2) and a lower base height (HT1). This is done to allow the program to check total sky cover as well as partial sky cover (sky cover between two base heights) with the same subroutine.

A uniform pattern of rays is put up to check the sky cover. These rays emanate from the ground-observer's origin and are defined by each ray's directional cosines (Appendix A). The ray pattern consists of 286 rays, which corresponds to a distance between rays of one-seventh radian on the unit hemisphere. By changing the distance between rays one can change the number of rays used. The maximum and minimum number of rays that can be used are 500 and 1, respectively. Statistically, the optimum choice is between 150 and 300 rays.

After the ray pattern is set up, each ray is compared with every cloud until it intersects (is covered) a cloud or all clouds are exhausted. Once

a ray is covered (since it is of no further interest), it is "tagged" and is not compared with any more clouds in this and future sky cover computations. when all of the rays have been compared for intersections with each cloud, the sky cloud cover is computed. Sky cover is the ratio of the number of covered rays to the total number of rays in the pattern.

3. Printer Plots of the Sky Cover Between Two Heights

After the sky cover is computed, the ray pattern can be transformed into a printer density plot. Points for the plot are generated by intersecting the uniform ray pattern with the placement hemisphere. These 3-space (X, Y, Z) points are then transformed into 2-space (X, Y) points (Figure 1). The transformation is such that the arc distance (r) from the pole to each point is preserved as a linear distance (r') from the Z-AXIS to each point. The longitude angle (ϕ) for each point is preserved as an angle (ϕ') between the X-AXIS and the projected distance r'.

Figure 2 is an example of a complete printer density plot. The periods are rays that did not intersect a cloud and the circles with plus signs in them are rays that did.

Like the sky cover computation, printer plots of the sky cover are made for clouds intersecting rays between two heights. In Figure 2, the heights are 0, and the maximum height a cloud top can be away rom the observer's origin. Thus, the total sky cover is displayed here.

4. Computing the Ground Cover

Ground cover is defined to be the percent or fraction of ground covered by an orthogonal projection of clouds (or parts of clouds) between two heights, UPHT and LWHT, onto the flat earth (X, Y plane).

To compute the ground cover, the X, Y plane is first set up so that the circle of cloud placement (the sphere of cloud placement when projected onto a plane is a circle) is fully contained within the grid.

Check points are the points where the X and Y parallel grid lines intersect. Starting in the upper left hand corner of Figure 3, CLOUDS works with the check points in horizontal rows until the lower right corner is reached. During processing CLOUDS determines whether a given check point is within the placement circle. If it is not, the check point is rejected and the program moves on to the next one. If the check point is within the cloud placement

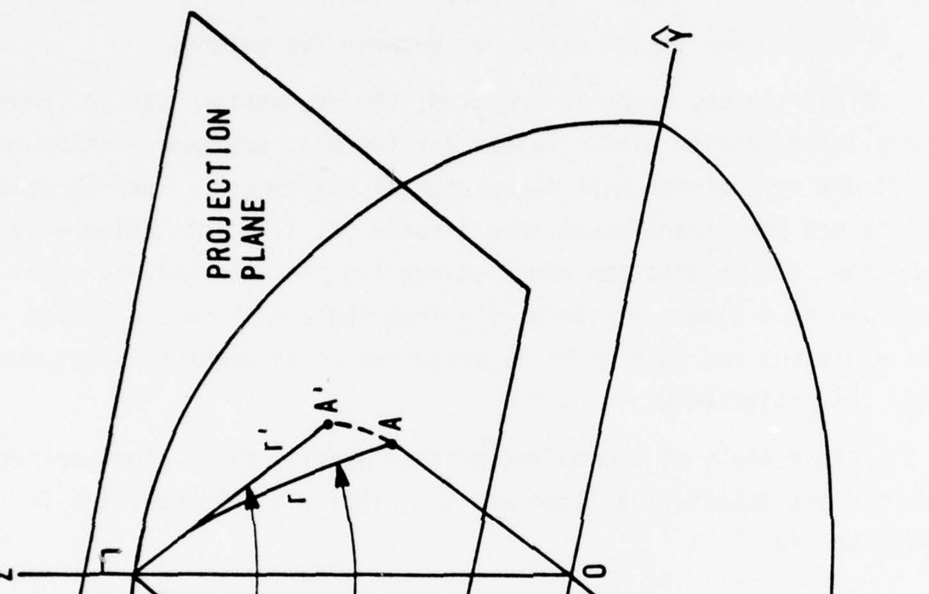
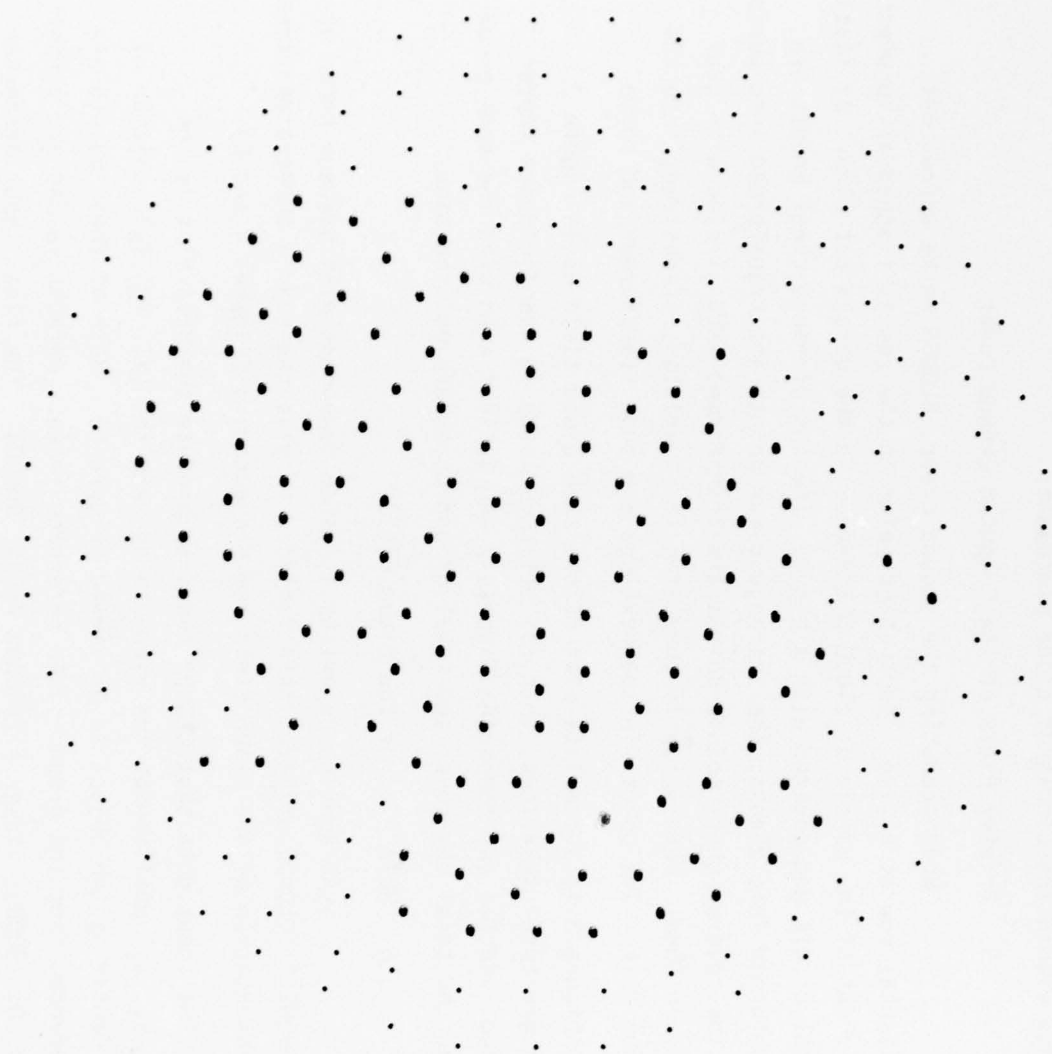


Figure 1. Projection of the Intersection (A) Between the Sphere of Cloud Placement and a Ray Onto the Translated X,Y Plane. The Coordinate System is that of the Ground-Based Observer.

THIS IS A PICTURE OF THE SKY AS SEEN THROUGH A UNIFORM HEMISPHERICAL COLANDER.
O-S DENOTE CLOUDS AND .-S DENOTE CLEAR SKY.



THE SKY HAS BEEN COMPLETED.
THE TOTAL SKY COVER IS 0.493006993

Figure 2. Sky Cover Density Plot for the Total Cloud Field.

circle, the clouds between the two given heights are inspected to see if one covers that check point. This inspection process continues until a cloud is found to cover the check point, or all the clouds are exhausted. After each check point has been examined, the ground cover can be computed. It is simply the number of covered check points divided by the number of check points within the circle of cloud placement.

5. Printer Plots of the Computed Ground Cover

When computing the ground cover, CLOUDS works across one horizontal row at a time. Each check point in the row is flagged as to whether it is out of the circle of cloud placement, in the circle but clear, or lastly, in the circle and covered with a cloud. The out-of-range check points are transformed into blanks; the in-range clear points are transformed into periods; and the covered check points points are transformed into circles with plus signs in them. When a row is completed it is written, if desired, into the output file. The points in the next row are then transformed and so on.

Figure 3 is a complete plot of the same cloud field as in Figure 2. Both are total sky views, that is, all the clouds in the field are represented. Notice (by comparing Figures 2 and 3) that even with the same cloud field the total sky cover and total ground cover are not the same.

6. META Plot of the Cloud Field

At AFWL there exists a system dependent plot package known as METAPLOT.* CLOUDS utilizes this facility to give the user a three-dimensional representation of the cloud field and trajectories (Figures 4 and 5).

The input data that CLOUDS needs to produce the META Plot is the (X_1, Y_1, Z_1) position of the viewer's eye and the (X_2, Y_2, Z_2) position of the center of the object to be viewed (Figure 6). Both of these points are referenced from the ground-based reference frame. Default values are center = (0, 0, 19000), viewer = (90000, 75000, 90000). The final input parameter CLOUDS needs to produce the META Plot is NPTS, the number of vertical lines used in drawing the clouds. The default value for NPTS is twelve. The METAPLOT output is placed on TAPE99.

NOTE: If CLOUDS is executed on any computer other than those at AFWL, the META Plot of the cloud field should not be activated.

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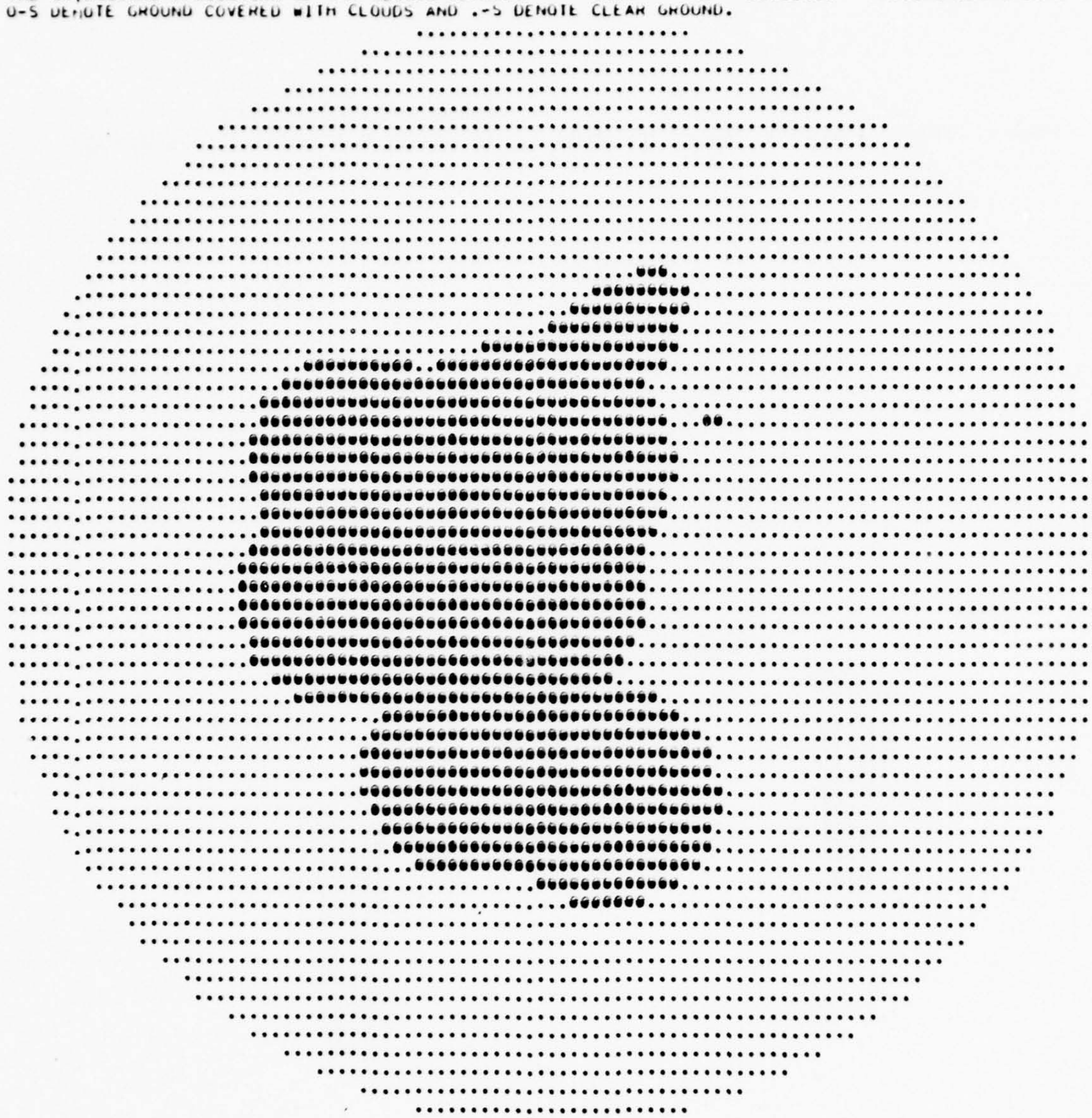
*Additional information on METAPLOT may be obtained by contacting Bob Conley at AFWL/DAP, Kirtland Air Force Base, NM, (505) 264-1307, Autovon 964-1307

THE ORTHOGONAL PROJECTION OF THE CLOUDS BETWEEN 0.00 AND 20000.00 METERS LOOKS LIKE THE FOLLOWING
0-S DENOTE GROUND COVERED WITH CLOUDS AND .-S DENOTE CLEAR GROUND.



THE GROUND COVER BETWEEN 0.00 AND 20000.00 METERS IS .226190476

Figure 3. Total Ground Cover Shown is for the Same Cloud Field Shown in Figure 2. Note that the Total Ground Cover is not the Same as the Total Sky Cover.

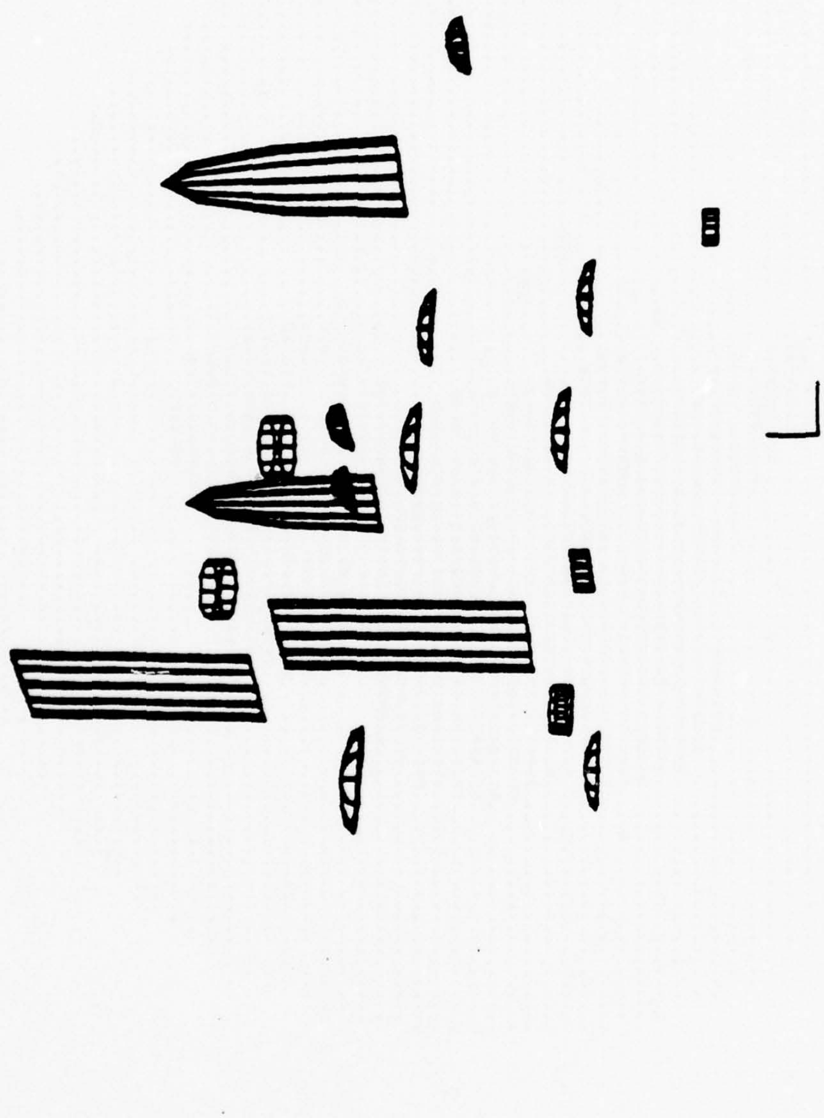


Figure 4. A View of a Cloud Field From Along the X-Axis. Viewer = (90000, 0, 0), Center (0, 0, 16000).

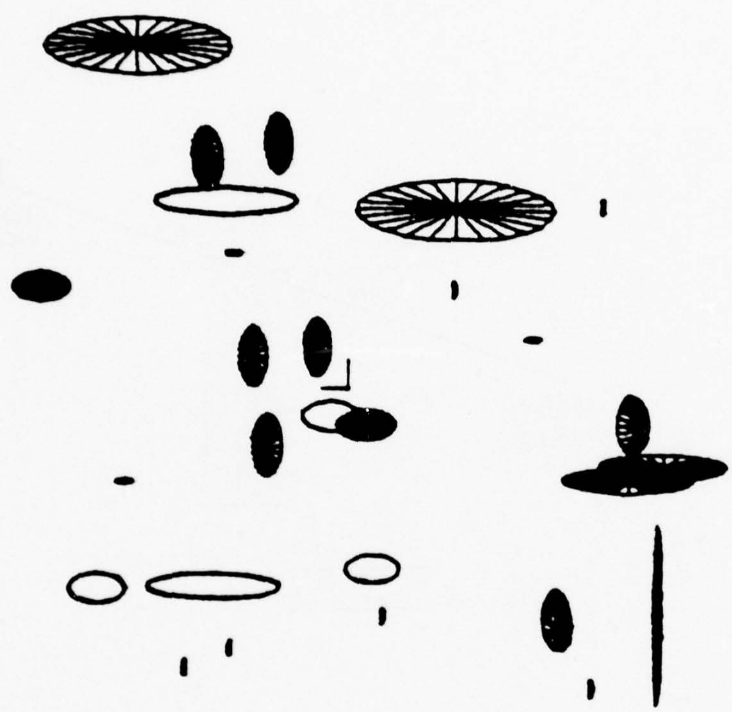


Figure 5. View of a Cloud Field From Along the Z-Axis (From Above). Viewer = (0, 0, 90000), Center = (0, 0, 16000).

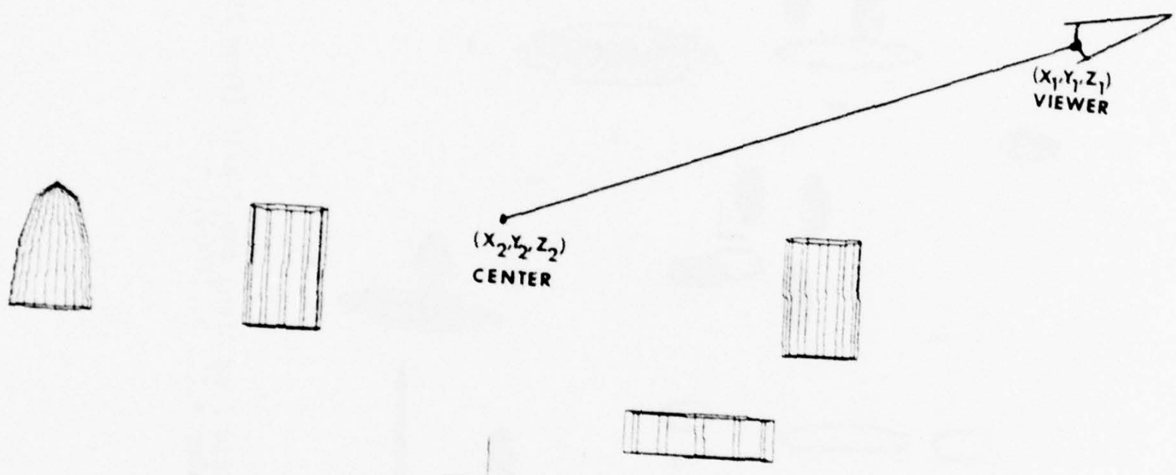


Figure 6. Graphical Representation of the Viewer's position and the Center of the Cloud Field.

B. SCENARIO GENERATION AND CFLOS CALCULATION BLOCK

1. Chase Model

Given two vehicles (i.e., their initial conditions) in the ground-based observer's reference frame, the chase model solves the hawk-pigeon pursuit differential equation problem. This problem arises by requiring the hawk (or aggressor, A) always to fly directly towards the pigeon (or defender, B) at all times.

Additional restrictions on the trajectories are: (1) the initial conditions on B (i.e., his speed, azimuth, and height) cannot be changed. Thus, B is restricted to a straight line of flight. (2) A's speed cannot change. The algorithm used to generate the chase model scenario data is discussed in detail in Appendix C. It should be noted here that if A's speed is not sufficiently larger than B's, the two vehicles will never meet.

2. Direct Intercept Model

The basic idea for this type of scenario generation is that both the defender and aggressor fly in straight lines and that the two vehicles must intersect at some instant of time. The additional restrictions on this model are identical to the restrictions on the chase model. For an in-depth look at this problem see Appendix A of Reference 1.

3. Scenario Data from TAP

TAP is a very sophisticated scenario generating program. It is beyond the scope of this report to discuss TAP in detail. More information about TAP is available in Reference 3.

The aspect of TAP that is within the scope of this report is its output. TAP has two types of output, one known as TACED (English units) and the other known as TAPED (SI units). The format in both types of output is identical and CLOUDS can utilize both.

When the TAP output is used for scenario data, it must have only one defender and may have up to four aggressors. Also, the data must be placed on a file (TAPE7) so that CLOUDS can read it.

---

3. Grant, J. N., and Olds, R.A., "Trajectory Analysis Program (TAP)", AFWL-TR-77-115, Air Force Weapons Laboratory, Kirtland Air Force Base, NM, 1977. (Also contact AFWL/LEAPS, (505) 264-2995)

The following is an example of how to prepare the TAP output (on a Permanent file called TACED4) for the CLOUDS program on a CDC CYBER 176 computer.

```
JOB
ACCOUNT
-
-
-
-
ATTACH (TAPE7, TACED4, ID = DYVMMKS)
REWIND (TAPE7)
-
LGO.
-
-
-
```

In the ATTACH statement, the TACED4 permanent file is given the logical file name TAPE7. The REWIND statement just assures that the pointers are positioned at the beginning of the file. The ATTACH must be positioned in the input stream before the LGO so that TAPE7 is set up before CLOUDS executes.

4. CFLOS Calculation

For CFLOS calculations only one aggressor at a time is considered. All of the CFLOS and DCFLOS calculations are performed on a given aggressor and then if there is more than one the procedure is repeated for each. The trajectories through the cloud field are contained in two arrays (one for the defender and one for the aggressor) as discrete points. The time between consecutive positions is Δt. CLOUDS starts with the first two data points, one on each trajectory, at time $t_0 = 0$. The distance between two points is then checked to see if it is within the user-specified maximum and minimum allowed (Section III.A). If not, this data is rejected, and the next point is then inspected. If the distance is within tolerance, the line

segment between the two data points, known as the line-of-sight (LOS) is found. This LOS is then compared with each cloud until an intersection is found or until all of the clouds are exhausted. The latter is known as cloud-free line-of-sight (CFLOS). The next two data points are inspected, and so on, until all of the trajectory points are exhausted.

The total percent of CFLOS is the number of cloud-free line-of-sights (within range) divided by the number of possible cloud-free line-of-sights (within range) times 100.

5. DCFLOS Calculations

DCFLOS is a consecutive CFLOS over some time interval $T = N\Delta t$ where $N > 2$.

In computing a CFLOS, CLOUDS sets up a flag array with one flag for each pair of positions. The flags are - 1, 0, and 1, and they correspond to out-of-range, in-range without a CFLOS, and in-range with a CFLOS, respectively.

To compute DCFLOS for some given times, T, which corresponds to $N\Delta t$, or N positions in the coordinate arrays of the vehicles, the flag array is inspected. The inspection starts at the first nonnegative array element and looks for continuous groups of N1's. In Figure 7, for example, $\Delta t = 0.2$ s and we want a DCFLOS for 0.8 s. This means N = 4, so we look for groups of 4 continuous 1's. There are 4 of these groups out of a total of 13 possible groups. Thus, for this example, the percent of 0.8 s DCFLOS is $\{(4/13)100 = 30.77 \text{ percent}\}$.

The times, T, for DCFLOS calculations are computed by starting T equal to $2\Delta t$ and incrementing by $2\Delta t$. Thus, T takes on the values of $2\Delta t$, $4\Delta t$, $6\Delta t$, etc.

Figure 7. LOS Flag Array Sample. The -1s indicate the LOS was out of range, the 1s indicate the LOS was in range and the sky was cloud free (CFLOS), and the 0s indicate that the LOS was in range but covered with a cloud.

If the DCFLOS for T goes to zero, computations are stopped. This is done since any larger T will also result in a zero DCFLOS. In Figure 7 any times larger than 1.4 seconds will result in a DCFLOS of zero.

6. Rotations

Once a cloud field has been generated it would be a tremendous waste to run the scenarios through it just once. Also, if the scenario was by chance oriented in the proper way, the LOS could pass through a group of clouds, or conversely, through a corridor between the clouds. Neither of these results would be representative of the real physical situation. Thus, in order to better utilize a generated cloud field and to minimize the odd situations the scenarios are rotated NOROT number of times about the Z-axis. The rotations are set up so that NOROT + 1 rotations bring each scenario back to its original (unrotated) configuration.

7. Plot of the Trajectory

If a METAPLOT plot is generated for the cloud field, the initial (unrotated) trajectory of the defender and each aggressor is plotted in the same plot frame. For details about plotting with the METAPLOT system, see Section II.A.6.

SECTION III

INPUT DATA STRUCTURE

The complete input data set for the CLOUDS computer program is divided into problem sets. There can be several problem sets in a data set. Each problem set is a complete problem in and of itself. It may or may not be related to any other problem in the data set.

Each problem set consists of eight types of Hollerith computer cards. Each card type has a specific field structure that is unique to that type of card. The fields on a card are read in under an NA1 format where N is the length of the field. Next, these Hollerith fields are translated into numbers. If the field is blank or contains alphanumeric (nonnumeric) symbols, then it is translated as a zero. This method allows the user some flexibility in placing numbers within the field (e.g., all integers do not have to be right justified), and also allows the use of code words instead of numbers.

The data fields used for each card type are described in Table 1. (Note: The International System of Units (SI) are used in the input data as well as throughout the program).

TABLE 1. DESCRIPTION OF HOLLERITH COMPUTER CARDS

Card Type	Card Columns	Variable Name	Description
1	1-80	NHEAD	A problem header statement. This statement is printed out on the first page of output.
2	1-2	NU1	The number of base heights $1 \leq NU1 \leq 15$.
	4-13	PERCNT	The total percent of sky cover that is desired, used only for method 1.
	14-17	PERCLD	The percent of cylindrical clouds to be placed. The percent of ellipsoidal clouds to be placed is then 100%-PERCLD.
	18-20	NU2	The number of possible different cloud dimensions $1 \leq NU2 \leq 100$.

TABLE 1. CONTINUED

Card Type	Card Columns	Variable Name	Description
3	1-10	BASHT(I)	The Ith height at which clouds are to be placed.
	11-13	PERCHT(I)	The percent of sky cover desired at this base height, used only for method 2.
	21-30	DENSTY(I)	The maximum density of a cloud at this base height (not used).
	31-36	FUN(I)	The name of a function that describes the density in a cloud as a function of distance from the center of the cloud (not used).

NOTE: There must be a cluster with NU1 cards of this card type in it.

Card Type	Card Columns	Variable Name	Description
4	1-10	L(I)	The X-length of the Ith cloud type in the cloud's reference frame.
	11-20	W(I)	The Y-width.
	21-30	T(I)	The Z-thickness.
	31-40	PHI(I)	The angle of rotation between the clouds reference frame and the ground based observer's refererence frame.
	41-43	PERCDM(I)	The percent of clouds that should have these dimensions. PERCDM(1) + PERCDM(2) + ... + PERCDM(NU2) = 100. This sum of 100 is a must!

NOTE: There must be a cluster with NU2 cards of this type in it.

Card Type	Card Columns	Variable Name	Description
5	1-3	NPTS	The number of vertical lines used to draw the clouds. If this input is not divisible by 4, it will be made so. (Default is 12.)
	5-14	VIEWER(1)	The X-Coordinate of the viewers position in terms of the ground based observer's reference frame.
	15-24	VIEWER(2)	The Y-Coordinate
	25-34	VIEWER(3)	The Z-Coordinate. Default for the viewers position is (90000, 75000, 90000)

TABLE 1. CONTINUED

Card Type	Card Columns	Variable Name	Description
	41-50	CENTER(1)	The X-Coordinate of the center of the plot frame in the ground based observer's reference frame.
	51-60	CENTER(2)	The Y-Coordinate.
	61-70	CENTER(3)	The Z-Coordinate. Default for the center's position is (0,0,16000).
	71-75	DUMMY	This is the flag that turns on the METAPLOT package. If DUMMY > 0 then the METAPLOT package is turned on (Default = 0, or off).
	76-80	DUMMY2	This flag turns on the printer plots. If DUMMY2 $\geq$ 0, then the printer plots are turned on. (Default is 0, or on).

NOTE: See Reference 3 for a complete definition of viewer and center.

Card Type	Card Columns	Variable Name	Description
6	1-5	DELT	The time increment between position calculations.
	6-10	DELTAT	The maximum time for which a continuous CFLOS (DFLOS) is calculated. (Default is the duration of the scenario).
	11-20	DMAX	The maximum range between aggressor and defender for which a CFLOS is calculated. (Default is 10000).
	21-30	DMIN	The minimum range between aggressor and defender for which a CFLOS is calculated. (Default is 100).
7	1-5	NOROT	The number of times (a maximum of 18) the scenario is rotated in the cloud field. (Default is 9).
	6-10	WHSCN	This variable is a flag for clouds. If it's positive, zero, or negative, the direct intercept model, the chase model, or data from the TAP file, respectively, will be used for scenario generation. (Default is the chase model).

NOTE: The rest of this card can be neglected if the direct intercept or chase models are used.

TABLE 1. CONTINUED

Card Type	Card Columns	Variable Name	Description
	11-15	NOCRFT	The number of aggressors on the TAP data file. This number plus the defender is the total number of crafts on the data file.
	16-20	IDENT	The number which identifies the defender (ownship) on the TAP data file.
	21-30	UNITS	The type of measurement units on the TAP data file. Possibilities are "ENGLISH" or "MKS". (Default is MKS).

NOTE: If the scenario data is coming off the TAP file, this card can be neglected (i.e., left blank), but still must be present.

Card Type	Card Columns	Variable Name	Description
8	1-10	DAB	The initial LOS distance between the defender (B) and the aggressor (A).
	11-15	ELEVA	The aggressor's initial elevation angle (in degrees) from the defenders line of flight.
	16-20	ATZMA	The aggressor's initial azimuth angle (in degrees) from the defenders line of flight.
	21-25	ATZMB	The defender's initial azimuth angle (in degrees) from the ground based observer's X-AXIS.
	26-30	VELA	The aggressor's speed during the scenario.
	31-35	VELB	The defender's speed during the scenario.
	36-40	HT	The defender's height above the ground.

B. INPUT OPTIONS

1. The following is a list of options that CLOUDS can execute:

a. Cloud Placement

(1) Clear Sky

(2) Overall Placement

(3) Placement by Base Height

b. Plotting

(1) METAPLOT - AFWL Dependent

(2) Printer Plots - Machine Independent

c. Scenario Generation

(1) Direct Intercept Model

(2) Chase Model

(3) TAP File

d. Multiple Runs

2. Turning on the Options

The cloud placement options are entered on the type 2 and 3 cards. If a clear sky is desired, columns 4-13 on the type 2 card should contain the code words CLEAR SKY. If overall placement is desired, the same columns on the type 2 card should contain a number between 0 and 100. In the latter, CLOUDS will ignore columns 11-13 on each type 3 card, which corresponds to the desired cloud cover at each base height (Figure 8). The user can only specify a total cloud cover or cloud cover at each base height. Default is total cloud cover. Thus, if placement by base height is desired, columns 4-13 on the type 2 card should be left blank and columns 11-13 on each type 3 card should contain a number between 0 and 100 (Figure 9).

The plotting options are entered in columns 71-80 on the type 5 card. Columns 1-70 all have defaults and can be left blank. If a METAPLOT plot of the sky is not wanted, columns 71-75 should be left blank or a negative value placed there. The METAPLOT package is turned on by placing a positive value in columns 71-75. The METAPLOT package is available only at AFWL and CLOUDS will abort with unsatisfied externals if the user tries to use METAPLOT at any other installation. The printer plots can be turned off only by placing a negative value in columns 76-80 of the type 5 card. If this field is left blank or a positive value is placed in it, the printer plots will be used.

```
Type 1  SAMPLE RUN WITH TOTAL PLACEMENT, MODELDI, PRINTER PLOTS, BUT NO META PLOTS.
Type 2  5  30          30 5
        20000     25
        17000     20
Type 3  15000     15
        13500     10
        4000      5
        2000      1800      6000      20        20
        10000     1000      700       30        20
Type 4  1500      200       800       40        20
        1700      100       9000      50        20
        25000     25000     5000      10        20
Type 5
Type 6  0.2  100  100000    100
Type 7  15   10
Type 8  100000    30   45   10   500  200  4500
Type 1  SAMPLE RUN WITH A CLEAR SKY, NO PLOTS, AND USING DIRECT INTERCEPT MODEL.
Type 2  1  CLEAR SKY         1
Type 3  10000
Type 4  100       100       100       45        100
Type 5                                                                              -100
Type 6  .5   425  150000    75
Type 7  6    10
Type 8  175000    15   30   20   300  100  10000
```

Figure 8. Two CLOUDS Problem Sets.

Two problems sets. In the first problem set: 30% total cloud cover, 5 base heights, 5 types of clouds, default plotting options, direct intercept model (a positive number in columns 6,7 in card type 7). In the second problem set: No clouds are to be placed (clear sky), 1 base height, 1 cloud type, printer plots turned off (all other plotting options default), and Direct Intercept Model.

```
    JAMIN,T40,P60,ST176.
A   ACCOUNT(SEAGER)
    REWIND(OUTPUT)
    ---------------------------------
    ATTACH(RUN),CLOUDS,ID=DYMSMKS)
B   UPDATE(F,P=RUN1)
    FTN(L=0,EL=A,ER,T,I)
    ---------------------------------
C   ATTACH(TAPE7,TACED4,ID=DYMSMKS)
    REWIND(TAPE7)
    ---------------------------------
    LDSET(PRESET=ZERO)
D   LIBRARY(METALIB)
    LGO.
    ---------------------------------
    REQUEST(TAPE2,*Q)
    REWIND(TAPE1,TAPE2)
    COPY(TAPE1,TAPE2)
    DISPOSE(TAPE2,*MF=PF8,ST=ANY)
E   REWIND(INPUT)
    COPYSBF(INPUT,OUTPUT)
    EXIT.
    REWIND(INPUT)
    COPYSBF(INPUT,OUTPUT)
    ---------------------------------
B   *IDENT TEST15
    ---------------------------------
    SAMPLE RUN WITH PLACEMENT BY LEVELS TAPDTA (ENGLISH UNITS) AND ALL PLOTS
     2              30 7
    6000        35
    10000       45
    10000       10000       1000        45        10
    1000        5000        5000        45        10
    5000        10000       6000        45        20
    1000        2000        500         45        20
    2000        1000        7000        45        20
    6000        3000        600         45        10
    900         5000        1000        45        10
    24  90000       75000       90000             16000                    10
     0.2  30    900000     100
    15     -10     4     3  ENGLISH
    BLANK CARD. MODLDI OR MODELC NOT USED
```

Figure 9. **CLOUDS Control Cards**

The control cards do the following. (1) notify the computer of the job (**A**), (2) **Prepare clouds** for execution (B), (3) Set up the Tap Data File (**C**), (4) Run the program (D), (5) Process the output, (E). The problem data set has: 2 base heights, by base heights (levels), 2 base heights, 7 types of clouds, all plots and scenario generation by tap with English units.

Printer plots are machine independent and can be used on any computer with an ANSI compiler (Figures 8 and 9).

One of three different scenario generation routines can be selected by placing a negative value, a zero, or a positive value in columns 6-10 of the type card 7. A negative value turns on the TAP file reading routine. Accompanying a negative value in this field should be the appropriate information in columns 11-30 on the same card (see Table 1). The type 8 card can then be left blank (but not deleted), as it will be read and ignored. If the TAP program is used, the scenario data generated by it must be entered in the TAPE7 file, so that CLOUDS can be read from it (Figure 9 gives an example of this for a CDC CYBER 176 computer).

The chase and direct intercept models can be turned on by placing a zero or positive value in columns 6-10 on the type 7 card, or by leaving the columns blank; CLOUDS will ignore the rest of the type 7 card.

The type 8 card must contain the information described in Table 1 for that type of card. Multiple runs can be executed by simply having more than one problem set in the input data set (Figure 8).

SECTION IV

OUTPUT DATA STRUCTURE

A. EXECUTION OUTPUT

Much output data are generated during execution of the cloud placement phase of the CLOUDS computer program. These data (messages) give the user a good idea of what went on during cloud placement. Should a fatal error occur during processing, the messages will point to the location of the problem. The order and the type of output messages depend on the method of cloud placement being used (Section II.A.1.a and b). The following is an explanation of the message for each method of cloud placement.

PROBLEM TITLE

This is the first program output after the input data has been checked and accepted.

CLOUD COVER MESSAGE

This message is written after each cloud has been placed. In Figure 10, starting from left to right, the numbers correspond to:

(1) The base height for each cloud (HT1),

(2) The upper height for each level's sky cover computation,

(3) The number of each cloud as it was placed, and

(4) The sky cover (between HT1 and HT2 for method 2 and total sky cover for method 1) for each cloud as it was placed.

Note in Figure 10, that the first cloud given the number 12 and 16 was thrown out and another given its index because the cloud placed first made the sky cover between 4000 m and 35000 m greater than the desired tolerance of 30 percent. If more than 10 clouds are thrown out, a user warning (similar to the one shown in Figure 11) is written out and placement of clouds in the next level commences (method 2) or the sky is considered completed (method 1 or method 2 when clouds are being placed in the uppermost base height).

BASE HEIGHT COMPLETE MESSAGE

In method 2, when the cloud cover at a base height has been completed (all clouds at that base height have been placed), a message (similar to the one shown in Figure 12) is written out.

```
SAMPLE RUN WITH TOTAL PLACEMENT, MODELUI, PRINTER PLOTS, BUT NO META PLOTS.
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  1   CLOUD IS .003496503
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  2   CLOUD IS .003496503
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  3   CLOUD IS .003496503
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  4   CLOUD IS .006993007
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  5   CLOUD IS .010489510
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  6   CLOUD IS .010489510
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  7   CLOUD IS .013986014
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  8   CLOUD IS .017482517
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER  9   CLOUD IS .020979021
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 10   CLOUD IS .024475524
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 11   CLOUD IS .027972028
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 12   CLOUD IS .374125874
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 12   CLOUD IS .027972028
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 13   CLOUD IS .031468531
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 14   CLOUD IS .031468531
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 15   CLOUD IS .031468531
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 16   CLOUD IS .405594406
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 16   CLOUD IS .482517483
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 16   CLOUD IS .164335664
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 17   CLOUD IS .202797203
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 18   CLOUD IS .241258741
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 19   CLOUD IS .241258741
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 20   CLOUD IS .241258741
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 21   CLOUD IS .241258741
THE COMPUTED SKY COVER BETWEEN   4000.00   AND   35000.00   METERS AFTER THE NUMBER 22   CLOUD IS .255244755
```


Figure 10. Cloud Placement Messages Detailing the Sky Cover After Each Cloud is Placed.

```
THE COMPUTED SKY COVER BETWEEN    4000.00    AND    35000.00    METERS AFTER THE NUMBER  61    CLOUD IS .192307692
THE COMPUTED SKY COVER BETWEEN    4000.00    AND    35000.00    METERS AFTER THE NUMBER  62    CLOUD IS .192307692
THE COMPUTED SKY COVER BETWEEN    4000.00    AND    35000.00    METERS AFTER THE NUMBER  63    CLOUD IS .762237762
///////// USER WARNINGS ////////// THE DESIRED CLOUD COVER BETWEEN    4000.00 METERS AND   35000.00 METERS
COULD NOT BE BROUGHT WITH IN TOLLERENCE.  THE LAST CLOUD WAS THROWN OUT.
THE FINAL CLOUD COVER FOR THIS BASE HEIGHT WAS .192307692
```

Figure 11. User Warning Message. This message notifies the user that the specified cloud cover could not be attained for a given lower and upper height.

```
THE SKY COVER FOR THE BASE HEIGHT AT    6000.00     METERS HAS BEEN COMPLETED.
CLOUDS WILL NOW BE PLACED IN THE NEXT BASE HEIGHT

THE COMPUTED SKY COVER FOR THE BASE HEIGHT AT   10000.00    METERS FROM CLOUDS COMMING UP FROM THE
BASE HEIGHT AT    6000.00    METERS IS .118881119
```

Figure 12. This Message is Written When Each Base Height is Completed.

RESIDUAL CLOUD COVER MESSAGE

Assuming again that method 2 is being used, when all clouds at a base height are placed, the cloud cover for the next base height is computed. Since no clouds have been placed in the new base height, the cloud cover computed here is from clouds coming up from below. This number is written to the output file with an appropriate message (Figure 12).

SKY COMPLETE MESSAGE

When the total sky cover is satisfied for method 1 or the sky covers for all base heights have been completed for method 2, the fraction of total sky cover is computed and written to the output file.

When method 1 is selected for cloud placement, the order of output is:

(1) Problem title.

(2) Cloud cover messages until the sky is completed. If desired, printer plots of the total sky cover is written to the output file.

(3) The cloud cover is computed between each two base heights. If desired printer plots of the cloud cover between each two base heights are written to the output file.

For method 2, the messages start out quite similar to those for method 1 but diverge rapidly. The order of output for method 2 is:

(1) Problem title.

(2) Cloud cover messages are generated until a base height is completed. If printer plots are being produced, the sky cover printer plot for this base height is written to the output file.

(3) A complete message is written out for each base height as it is completed.

(4) If the uppermost base height has not been reached, the residual cloud cover is computed for the next higher base height and printed. Number 2 messages are generated until all of the base heights are completed.

(5) The total sky cover is computed and, if desired, the total cloud cover printer plot is generated.

At this point methods 1 and 2 become similar again; both go on to the ground cover determinations (Section II.A.4 and 5), which consist of:

(1) total ground cover, and (2) ground cover due to clouds between base heights.

```
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  1 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  1 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  2 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  2 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  3 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  3 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  3 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  4 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  4 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  4 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  5 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  5 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  5 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  6 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  6 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  6 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  7 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  7 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  7 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  8 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  8 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  8 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER  9 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  9 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER  9 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 10 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 10 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 10 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 11 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 11 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 11 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 12 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 12 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 12 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 13 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 13 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 13 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 14 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 14 ROTATION HAS BEEN GENERATED.
THE DELTA CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 14 ROTATION HAS BEEN GENERATED.
THE SCENARIO DATA FOR THE NUMBER  1 AGGRESSOR HAS BEEN ROTATED FOR THE NUMBER 15 TIME.
THE CFLOS DATA FOR THE NUMBER  1 AGGRESSOR AND THE NUMBER 15 ROTATION HAS BEEN GENERATED.
```

Figure 13. Scenario, Rotation and CFLOS Generation Messages. Each Message is Printed after the Activity it Describes is Completed.

Table 2. Descriptive Data for Each Cloud Placed.

THE FOLLOWING IS A LIST OF THE DIMENSIONS FOR EACH CLOUD

CLOUD	X-LENGTH	Y-WIDTH	Z-THICKNESS	ANG OF ROT	X-POS.	Y-POS.	Z-POS.	TYPE
1	1000.00	5000.00	5000.00	45.00	-1750.31	7760.01	6000.00	ELLIP
2	1000.00	2000.00	500.00	45.00	-8631.51	12429.85	6000.00	ELLIP
3	2000.00	1000.00	7000.00	45.00	-10338.90	2579.66	6000.00	ELLIP
4	10000.00	10000.00	6000.00	45.00	-1250.11	-10602.87	6000.00	CYLIND
5	10000.00	10000.00	1000.00	45.00	-5834.95	7360.32	6000.00	ELLIP
6	1000.00	2000.00	500.00	45.00	-10093.61	4604.21	10000.00	ELLIP
7	1000.00	2000.00	500.00	45.00	-8185.47	13966.08	10000.00	ELLIP
8	1000.00	2000.00	500.00	45.00	-499.17	6970.88	10000.00	ELLIP
9	1000.00	2000.00	500.00	45.00	-13606.24	12817.98	10000.00	ELLIP
10	900.00	5000.00	1000.00	45.00	-13220.22	-6322.22	10000.00	ELLIP
11	10000.00	10000.00	6000.00	45.00	-10183.86	4537.88	10000.00	ELLIP
12	10000.00	10000.00	6000.00	45.00	-11240.92	-15201.27	10000.00	ELLIP
13	10000.00	10000.00	6000.00	45.00	18299.97	-11110.56	10000.00	ELLIP
14	2000.00	1000.00	7000.00	45.00	-2268.86	-9610.37	10000.00	ELLIP
15	10000.00	10000.00	1000.00	45.00	939.46	-2472.41	10000.00	CYLIND
16	1000.00	2000.00	500.00	45.00	-7175.56	18731.37	10000.00	CYLIND
17	5000.00	10000.00	6000.00	45.00	-10396.51	16490.31	10000.00	CYLIND
18	1000.00	2000.00	500.00	45.00	-343.23	-10859.48	10000.00	ELLIP
19	10000.00	10000.00	6000.00	45.00	7841.23	-18029.20	10000.00	ELLIP
20	1000.00	2000.00	500.00	45.00	-5705.89	5433.30	10000.00	ELLIP
21	2000.00	1000.00	7000.00	45.00	1192.37	9369.85	10000.00	ELLIP
22	1000.00	2000.00	500.00	45.00	3432.50	-6038.57	10000.00	ELLIP
23	10000.00	10000.00	1000.00	45.00	-19342.17	-5422.84	10000.00	ELLIP
24	1000.00	2000.00	500.00	45.00	-3322.94	4739.60	10008.00	ELLIP
25	2000.00	1000.00	7000.00	45.00	728.48	19603.99	10000.00	ELLIP
26	2000.00	1000.00	7000.00	45.00	20610.20	-8388.19	10000.00	ELLIP
27	900.00	5000.00	1000.00	45.00	19295.68	-9751.45	10000.00	ELLIP
28	1000.00	2000.00	500.00	45.00	11075.30	-11275.65	10000.00	ELLIP
29	900.00	5000.00	1000.00	45.00	-11870.59	-3331.20	10000.00	CYLIND

```
    NU1...THE NUMBER OF BASE HEIGHTS
 PERCNT...THE TOTAL PERCENT OF DESIRED SKY COVER
 PERCLU...THE PERCENT OF CYLINDERS TO BE BUILT
   NU2...THE NUMBER OF INPUT CLOUD DIMENSIONS

NU1 PERCNT  PERCLD    NU2

 5    50.0    30.0     5

  BASHT(I)...AN ARRAY CONTAINING ALL THE POSSIBLE BASE HEIGHTS
 PERCHT(I)...THE PERCENT OF DESIRED CLOUD COVER AT THE ITH BASE HEIGHT
 DENSTY(I)...AN ARRAY CONTAINING THE POSSIBLE MAXIMIM DENSITYS FOR CLOUDS
    FUN(I)...AN ARRAY CONTAINING THE NAMES OF FUNCTIONS DESCRIBING THE DENSITY FALL OFF IN A  CLOUD

LOUD        BASHT          PERCHT         DENSTY        FUN
  1        4000.00         500.00            .00    ::::::::::
  2       13500.00        1000.00            .00    ::::::::::
  3       15000.00        1500.00            .00    ::::::::::
  4       17000.00        2000.00            .00    ::::::::::
  5       20000.00        2500.00            .00    ::::::::::

LOUD NO      X-LENGTH        Y-WIDTH  Z-THICKNESS  ANG OF ROT  PER DIM
      1       2000.00        1800.00      6000.00       20.00    20.00
      2      10000.00        7000.00       700.00       30.00    20.00
      3       1500.00         900.00       800.00       40.00    20.00
      4       1700.00         900.00      9000.00       50.00    20.00
      5      25000.00       25000.00      5000.00       10.00    20.00

        NPTS...THE NUMBER OF LINES USED IN DRAWING EACH CLOUD
   VIEWER(1)...THE X COORDINATE OF THE VIEWERS POSITION IN THE TOPOCENTRIC FRAME
   VIEWER(2)...THE Y COOORDINATE OF THE VIEWERSPOSITION IN THE TOPOCENTRIC FRAME
   VIEWER(3)...THE Z-COORDINATE OF THE VIEWERS POSITION IN THE TOPOCENTRIC FRAME
   CENTER(1)...THE X-COORDINATE OF THE CENTER OF THE PLOT PICTURE IN THE TOPOCENTRIC FRAME
   CENTER(2)...THE Y-COORDINATE OF THE PLOT PICTURE IN THE TOPOCENTRIC FRAME
   CENTER(3)...THE Z-COORDINATE OF THE PLOT PICTURE IN THE TOPOCENTRIC FRAME

NPTS      VIEWER(1)        VIEWER(2)        VIEWER(3)       CENTER(1)       CENTER(2)       CENTER(3)
 12        90000.00         75000.00         90000.00            0.00            0.00        16000.00

 THE TIME BETWEEN POSITION CALCULATIONS WAS   .67291 SECONDS
THE MAXIMUM TIME FOR WHICH A DELTA CFLOS WAS CALCULATED WAS 100.00000 SECONDS.
THE MAXIMUM AND MINIMUM RANGES FOR A CFLOS CALCULATION WAS 100000.00 METERS    100.00 METERS RESPECTIVELY.
 THE NUMBER OF TIMES THE SCENARIO WAS ROTATED WAS      15

 ///// METHOD 1, TOTAL SKY CLOUD PLACEMENT, WAS CHOSEN FOR THE CLOUD FIELD GENERATION BLOCK /////

 ///// THE DIRECT INTERCEPT MODEL WAS CHOSEN FOR SCENERIO GENERATION /////

 THE INITIAL LINE OF SIGHT DISTANCE WAS   100000.0 METERS.
A-S ELEVATION ANGLE FORM B-S LINE OF FLIGHT WAS   30.00000 DEGREES
A-S ATZMUTH ANGLE FROM B-S LINE OF FLIGHT WAS   45.00000 DEGREES
B-S ATZMUTH ANGLE WITH THE X-AXIS WAS   10.00000 DEGREES
A-S AND B-S VELOSITY WAS    500.000        200.000METERS/SEC RESPECTIVELY.
A-S ELEVATION ABOVE THE GROUND WAS    4500.00

           SKYCVR.       TOTAL    GRN CVR.
  TOTAL    AT EACH      GROUND    AT EACH.
 KY CVR.   BASE HT.      COVER    BASE HT.
  50.70       0.00       25.95        0.00
             50.70                   25.95
             45.10                   23.74
             27.27                   13.27
              0.00                     .11
```

Figure 14. Translated Input Data for a Sample Problem Set.

Table 3. First Aggressor CFLOS Calculations

FOR THE NUMBER 1 AGGRESSOR THE FOLLOWING ARE THE CFLOS CALCULATIONS FOR EACH ROTATION(S).

NOROT	TOTAL CFLOS	LONGEST CFLOS	NO. OF OCC.
1	31.32530	51.81444	1
2	39.75904	65.94[illegible]65	1
3	52.61044	87.47893	1
4	66.66667	111.03095	1
5	79.51807	132.56422	1
6	90.36145	150.73292	1
7	98.79518	164.86413	1
8	100.00000	166.88288	1
9	100.00000	166.88288	1
10	100.00000	166.88288	1
11	100.00000	166.88288	1
12	86.74699	144.67669	1
13	64.25703	106.99346	1
14	44.17671	73.34772	1
15	32.12851	53.16027	1

FOR THE NUMBER 1 AGGRESSOR THE VALUES OF THE DELTA CFLOS CALCULATIONS FOR TIMES
STARTING AT .67 SECONDS AND INCRAMENTED BY 1.35 SECONDS ARE THE FOLLOWING.

TIME	ROTATIONS 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	30.65	39.11	52.02	66.13	79.03	89.92	98.39	99.60	99.60	99.60	99.60	86.29	63.71	43.55	31.45
2	30.08	38.62	51.63	65.85	78.86	89.84	98.37	99.59	99.59	99.59	99.59	86.18	63.41	43.09	30.89
3	29.51	38.11	51.23	65.57	78.69	89.75	98.36	99.59	99.59	99.59	99.59	86.07	63.11	42.62	30.33
4	28.93	37.60	50.83	65.29	78.51	89.67	98.35	99.59	99.59	99.59	99.59	85.95	62.81	42.15	29.75
5	28.33	37.08	50.42	65.00	78.33	89.58	98.33	99.58	99.58	99.58	99.58	85.83	62.50	41.67	29.17
6	27.73	36.55	50.00	64.71	78.15	89.50	98.32	99.58	99.58	99.58	99.58	85.71	62.18	41.18	28.57
7	27.12	36.02	49.58	64.41	77.97	89.41	98.31	99.58	99.58	99.58	99.58	85.59	61.86	40.68	27.97
8	26.50	35.47	49.15	64.10	77.78	89.32	98.29	99.57	99.57	99.57	99.57	85.47	61.54	40.17	27.35
9	25.86	34.91	48.71	63.79	77.59	89.22	98.28	99.57	99.57	99.57	99.57	85.34	61.21	39.66	26.72
10	25.22	34.35	48.26	63.48	77.39	89.13	98.26	99.57	99.57	99.57	99.57	85.22	60.87	39.13	26.09
11	24.56	33.77	47.81	63.16	77.19	89.04	98.25	99.56	99.56	99.56	99.56	85.09	60.53	38.60	25.44
12	23.89	33.19	47.35	62.83	76.99	88.94	98.23	99.56	99.56	99.56	99.56	84.96	60.18	38.05	24.78
13	23.21	32.59	46.88	62.50	76.79	88.84	98.21	99.55	99.55	99.55	99.55	84.82	59.82	37.50	24.11
14	22.52	31.98	46.40	62.16	76.58	88.74	98.20	99.55	99.55	99.55	99.55	84.68	59.46	36.94	23.42
15	21.82	31.36	45.91	61.82	76.36	88.64	98.18	99.55	99.55	99.55	99.55	84.55	59.09	36.36	22.73
16	21.10	30.73	45.41	61.47	76.15	88.53	98.17	99.54	99.54	99.54	99.54	84.40	58.72	35.78	22.02
17	20.37	30.09	44.91	61.11	75.93	88.43	98.15	99.54	99.54	99.54	99.54	84.26	58.33	35.19	21.30
18	19.63	29.44	44.39	60.75	75.70	88.32	98.13	99.53	99.53	99.53	99.53	84.11	57.94	34.58	20.56
19	18.87	28.77	43.87	60.38	75.47	88.21	98.11	99.53	99.53	99.53	99.53	83.96	57.55	33.96	19.81
20	18.10	28.10	43.33	60.00	75.24	88.10	98.10	99.52	99.52	99.52	99.52	83.81	57.14	33.33	19.05
21	17.31	27.40	42.79	59.62	75.00	87.98	98.08	99.52	99.52	99.52	99.52	83.65	56.73	32.69	18.27
22	16.50	26.70	42.23	59.22	74.76	87.86	98.06	99.51	99.51	99.51	99.51	83.50	56.31	32.04	17.48
23	15.69	25.98	41.67	58.82	74.51	87.75	98.04	99.51	99.51	99.51	99.51	83.33	55.88	31.37	16.67
24	14.85	25.25	41.09	58.42	74.26	87.62	98.02	99.50	99.50	99.50	99.50	83.17	55.45	30.69	15.84
25	14.00	24.50	40.50	58.00	74.00	87.50	98.00	99.50	99.50	99.50	99.50	83.00	55.00	30.00	15.00
26	13.13	23.74	39.90	57.58	73.74	87.37	97.98	99.49	99.49	99.49	99.49	82.83	54.55	29.29	14.14
27	12.24	22.96	39.29	57.14	73.47	87.24	97.96	99.49	99.49	99.49	99.49	82.65	54.08	28.57	13.27
28	11.34	22.16	38.66	56.70	73.20	87.11	97.94	99.48	99.48	99.48	99.48	82.47	53.61	27.84	12.37
29	10.42	21.35	38.02	56.25	72.92	86.98	97.92	99.48	99.48	99.48	99.48	82.29	53.13	27.08	11.46
30	9.47	20.53	37.37	55.79	72.63	86.84	97.89	99.47	99.47	99.47	99.47	82.11	52.63	26.32	10.53
31	8.51	19.68	36.70	55.32	72.34	86.70	97.87	99.47	99.47	99.47	99.47	81.91	52.13	25.53	9.57
32	7.53	18.82	36.02	54.84	72.04	86.56	97.85	99.46	99.46	99.46	99.46	81.72	51.61	24.73	8.60
33	6.52	17.93	35.33	54.35	71.74	86.41	97.83	99.46	99.46	99.46	99.46	81.52	51.09	23.91	7.61
34	5.49	17.03	34.62	53.85	71.43	86.26	97.80	99.45	99.45	99.45	99.45	81.32	50.55	23.08	6.59
35	4.44	16.11	33.89	53.33	71.11	86.11	97.78	99.44	99.44	99.44	99.44	81.11	50.00	22.22	5.56
36	3.37	15.17	33.15	52.81	70.79	85.96	97.75	99.44	99.44	99.44	99.44	80.90	49.44	21.35	4.49
37	2.27	14.20	32.39	52.27	70.45	85.80	97.73	99.43	99.43	99.43	99.43	80.68	48.86	20.45	3.41
38	1.15	13.22	31.61	51.72	70.11	85.63	97.70	99.43	99.43	99.43	99.43	80.46	48.28	19.54	2.30
39	0.00	12.21	30.81	51.16	69.77	85.47	97.67	99.42	99.42	99.42	99.42	80.23	47.67	18.60	1.16
40	0.00	11.18	30.00	50.59	69.41	85.29	97.65	99.41	99.41	99.41	99.41	80.00	47.06	17.65	0.00
41	0.00	10.12	29.17	50.00	69.05	85.12	97.62	99.40	99.40	99.40	99.40	79.76	46.43	16.67	0.00
42	0.00	9.04	28.31	49.40	68.67	84.94	97.59	99.40	99.40	99.40	99.40	79.52	45.78	15.66	0.00
43	0.00	7.93	27.44	48.78	68.29	84.76	97.56	99.39	99.39	99.39	99.39	79.27	45.12	14.63	0.00
44	0.00	6.79	26.54	48.15	67.90	84.57	97.53	99.38	99.38	99.38	99.38	79.01	44.44	13.58	0.00
45	0.00	5.63	25.63	47.50	67.50	84.38	97.50	99.37	99.37	99.37	99.37	78.75	43.75	12.50	0.00
46	0.00	4.43	24.68	46.84	67.09	84.18	97.47	99.37	99.37	99.37	99.37	78.48	43.04	11.39	0.00
47	0.00	3.21	23.72	46.15	66.67	83.97	97.44	99.36	99.36	99.36	99.36	78.21	42.31	10.26	0.00
48	0.00	1.95	22.73	45.45	66.23	83.77	97.40	99.35	99.35	99.35	99.35	77.92	41.56	9.09	0.00
49	0.00	.66	21.71	44.74	65.79	83.55	97.37	99.34	99.34	99.34	99.34	77.63	40.79	7.89	0.00
50	0.00	0.00	20.67	44.00	65.33	83.33	97.33	99.33	99.33	99.33	99.33	77.33	40.00	6.67	0.00

THE RANDOM NUMBER GENERATOR WAS PRESET WITH 15.30.21.

Table 4. First Aggressor DCFLOS Calculations

During each ground cover computation a printer plot can be generated and written to the output file.

The cloud generation phase of execution has now been completed, and the scenario generation and CFLOS calculations begin. The messages for this phase are self-explanatory (Figure 13).

B. POST EXECUTION OUTPUT

This phase of output displays the important data generated in a problem set. The post execution output (Table 2) contains all of the descriptive data for each cloud. Table 2 gives the user, along with the execution output cloud cover messages, useful information about each cloud. Next, the input data, as translated and used by CLOUDS, are listed (Figure 14). For a complete description of the input data, see Section III. The input data are followed by a table containing a summary of the sky and ground covers, both total coverage and coverage between base heights.

The results of the CFLOS calculations are then written in the form of two tables for each aggressor. The first table (Table 3) contains the percent of total CFLOS and the longest continuous CFLOS in seconds for each rotation. The third column in this table contains the number of times the longest continuous CFLOS occurred. The next table (Table 4) contains the percent of DCFLOS for different times and rotations. The times for each DCFLOS are found by taking the integer under the heading TIME and multiplying it by the time increment.

After the DCFLOS table for the last aggressor is listed, the preset random number generator is printed. This number is the time that CLOUDS started computing. If the user desired to duplicate a run exactly, this number must be placed in the variable ITIME before the call to RANSET on the main program. The format for setting ITIME is:

ITIME = 10HƀHH.MM.SS.

In the output message for the random number generator, the last period is part of the preset variable ITIME, not punctuation, and must be in the setting for ITIME.

APPENDIX A
THE RAY PATTERN

It will become evident in Appendix B that a very important tool is needed to check the sky cover after each cloud is placed. This tool is a "UNIFORMLY" distributed ray pattern.* The generation of a ray pattern that is perfectly uniform is a very interesting and quite involved statistical problem. Since the CFLOS problem, rather than the perfectly uniform ray pattern problem, was our main concern an approximation to the perfectly uniform ray pattern was developed.

The approximation is based on the rather simple idea that the intersections of the rays and unit hemisphere should be equally spaced on equally spaced latitude lines. To implement this, the following algorithm was used:

Let D be the arc distance between latitudes. Then the equally spaced latitudes can be generated by starting at the zenith (or Z-axis) and incrementing along the spheres surface by D (Figure A-1). At each latitude the points of intersection are to be equally spaced so that D must be slightly adjusted. Let NMAX be the number of intersections on a given latitude and DLON the increments between the intersections, then NMAX and DLON are given by:

$$\mathrm{NMAX} = \mathrm{IFIX}(2\pi*\mathrm{SIN}(\mathrm{N}*\mathrm{D})/\mathrm{D} + 0.5)$$
$$\mathrm{DLON} = 2\pi*\mathrm{SIN}(\mathrm{N}*\mathrm{D})/\mathrm{FLOAT}(\mathrm{NMAX})$$

Where N is the number of the latitude line. Points of intersection are placed on a latitude line by starting on the longitude line that lies in the X-Z plane and incrementing around the latitude line by increments of DLON. To make the problem more uniform this process is done on every other latitude line (the odd numbered ones). For the even numbered latitude lines the first incremental distance from the X-Z longitude line is DLON/2, but everything else remains the same.

When generating a ray pattern it is desirable to use directional cosines for each ray. See Appendix B for a definition of directional cosine. Suppose we have a point of intersection, P, as labeled in Figure A-1. Then, the

*A uniformly distributed ray pattern refers to a ray pattern that when intersected with the unit hemisphere, gives any two areas, with the same size, the same probability of having a ray intersect the surface within them.

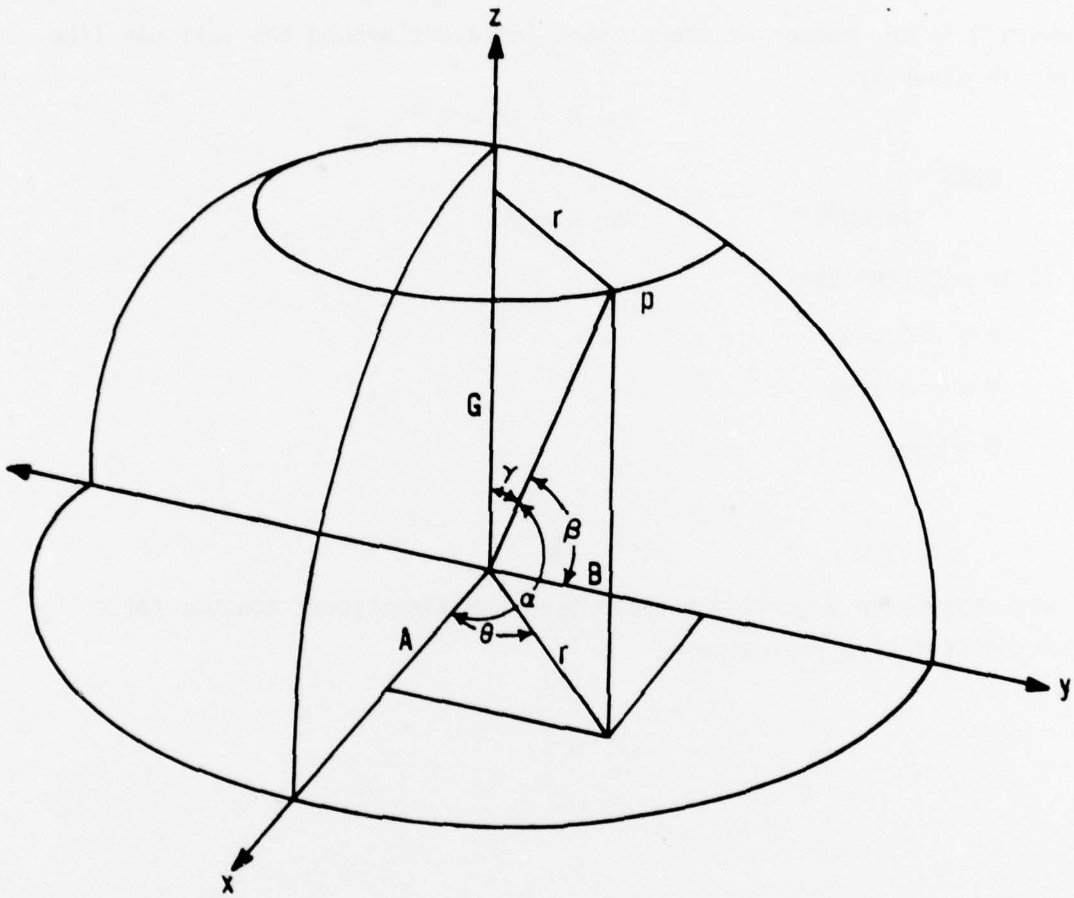


Figure A-1. The Direction Cosines (α, β, γ) for a Ray Intersecting the Unit Hemisphere at the Point P.

directional cosines for the ray that intersects the unit hemisphere to produce P, are A, B, and G. To find these distances we need γ and θ. These are given by:

$$\gamma = N * D$$

$$\theta = (M * DLON + BIAS)/r$$

where M is the number of the present increment around the latitude line and BIAS is given by:

$$BIAS = \begin{cases} 0 & \text{for } N = 2K + 1 \\ DLON/2 & \text{for } N = 2K \end{cases}$$

Thus, it is apparent that

$$A = r * \cos\theta$$

$$B = r * \sin\theta$$

$$G = \cos\gamma$$

Where

$$r = \sin\gamma$$

Thus, with the above algorithm one can find the directional cosines for a UNIFORMLY distributed ray pattern.

APPENDIX B

INTERSECTIONS

When computing sky cover a number of rays are sent out (Appendix A) and each ray that has not previously been covered is checked against each cloud until an intersection is found (thereby covering the ray). Clouds are represented by rotated truncated ellipsoids (only the upper half is used) and rotated elliptical cylinders. Thus, for computational speed it is imperative that the solution to these equations of intersection be developed and written in a form best suited for numerical evaluation. What follows is such a development. First, the equation for the ray-rotated elliptical cylinder intersection in three-dimensional space:

$$\frac{(X\cos\phi + Y\sin\phi - X1)^2}{L^2} + \frac{(-X\sin\phi + Y\cos\phi - Y1)^2}{W^2} = 1 \qquad \text{(B-1)}$$

$$Z1 \leq Z \leq Z1 + T$$

Where L, W, and T are the length, width, and thickness, respectively of the cloud in the primed reference frame (Figure B-1); and ϕ is the angle of rotation between the primed (cloud centered) reference frame and the observers reference frame. The restriction on Z makes the rotated ellipse into a rotated elliptical cylinder.

The equations of a line in three-dimensional space is given by:

$$X = \alpha t + P1$$

$$Y = \beta t + P2 \qquad \text{(B-2)}$$

$$Z = \gamma t + P3$$

Where

$$\alpha = \cos\Theta$$

$$\beta = \cos\delta$$

$$\gamma = \cos\xi$$

Thus α, β, γ are the directional cosines of the ray originating at (P1, P2, P3).

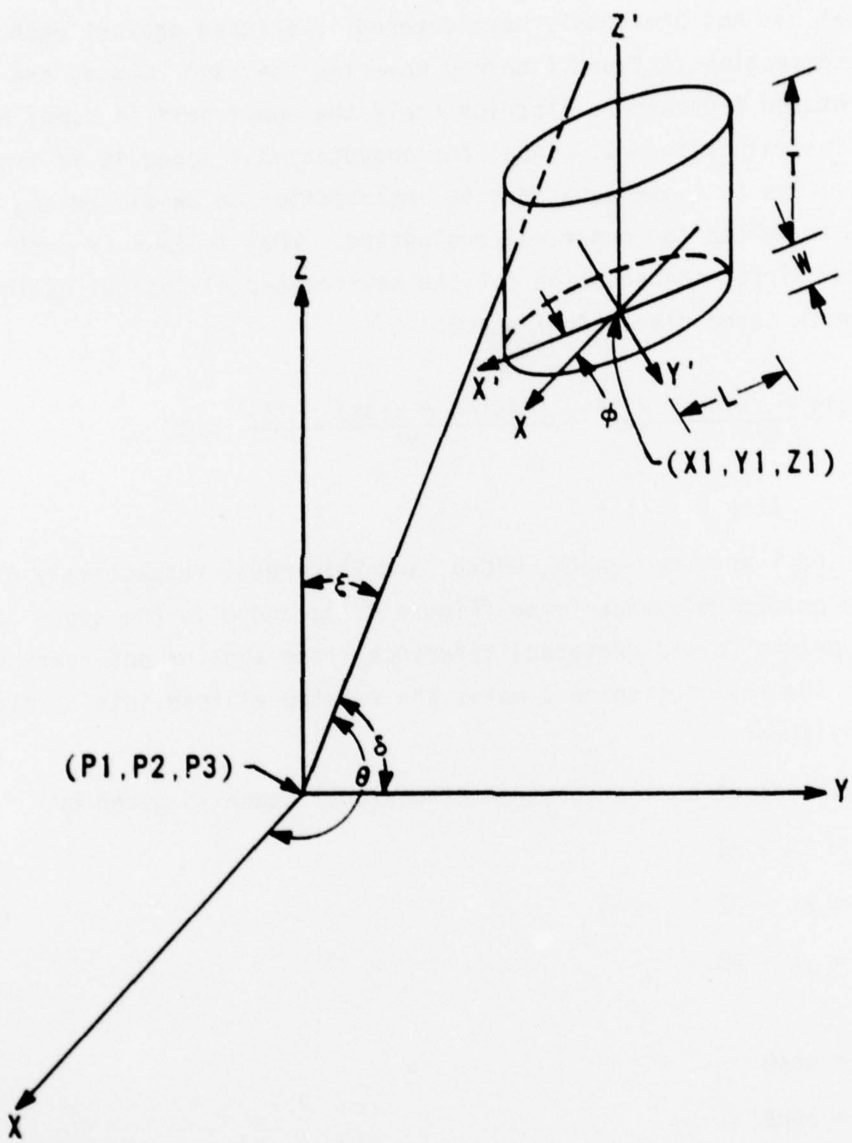


Figure B-1. A Cloud-Ray Intersection.

Substituting Equation B-2 into Equation B-1 yields a quadratic equation in t as follows:

$$(A_1\alpha^2 + A_2\beta^2 + A_3\gamma^2 + A_4\alpha\beta)\ t^2 + (B_1\alpha + B_2\beta + B_3\gamma + B_4\alpha P1 + B_5\alpha P2 + B_6\beta P1\ B_7\beta P2 + B_8\gamma P3)\ t + (C_1 P1^2 + C_2 P2^2 + C_3 P3^2 + C_4 P1P2 + C_5 P1 + C_6 P2 + C_7 P3 + C_8) = 0 \qquad \text{(B-3)}$$

Where

$A_1 = W^2\cos^2\phi + L^2\sin^2\phi$

$A_2 = W^2\sin^2\phi + L^2\cos^2\phi$

$A_3 = 2\cos\phi\sin\phi(W^2 - L^2)$

$A_4 = 0$

$B_1 = -2(X1W^2\cos\phi - Y1L^2\sin\phi)$

$B_2 = -2(X1W^2\sin\phi + Y1L^2\cos\phi$

$B_3 = 0 \qquad = A_4$

$B_4 = 2(W^2\cos^2\phi + L^2\sin^2\phi) \qquad = 2A_1$

$B_5 = 2\cos\phi\sin\phi(W^2 - L^2) \qquad = A_3$

$B_6 = 2\cos\phi\sin\phi(W^2 - L^2) \qquad = A_3$

$B_7 = 2(W^2\sin^2\phi + L^2\cos^2\phi) \qquad = 2A_2$

$B_8 = 0 \qquad = 2A_4$

$C_1 = W^2\cos^2\phi + L^2\sin^2\phi \qquad = A_1$

$C_2 = W^2\sin^2\phi + L^2\cos^2\phi \qquad = A_2$

$C_3 = 0 \qquad = A_4$

$C_4 = 2\sin\phi\cos\phi(W^2 - L^2) \qquad = A_3$

$C_5 = -2(W^2X1\cos\phi - L^2Y1\cos\phi) \qquad = B_1$

$C_6 = -2(W^2X1\sin\phi + 2L^2Y1\cos\phi) \qquad = B_2$

$C_7 = 0 \qquad = B_3$

$C_8 = L^2(X1 - W)\ (Y1 + W) + W^2X1^2$

In developing the ray-rotated truncated ellipsoid intersection a full (Nontruncated) rotated ellipsoid will be used. Thus, after intersections are found they must be checked to make sure they lie in the upper half of the full ellipsoid. The equation for a rotated ellipsoid in three-dimensional space is:

$$\frac{(X\cos\phi+Y\sin\phi-X1)^2}{L^2} + \frac{(-X\sin\phi+Y\cos\phi-Y1)^2}{W^2} + \frac{(Z-Z1)^2}{T^2} = 1 \qquad \text{(B-4)}$$

Substituting equation (B-2) into equation (B-4) yields a quadratic equation in t equivalent to equation (B-3), where the A's, B's and C's are defined as follows:

$$\begin{array}{lll}
A_1 = & T^2(W^2\cos^2\phi + L^2\sin^2\phi) & \\
A_2 = & T^2(W^2\sin^2\phi + L^2\cos^2\phi) & \\
A_3 = & 2T^2\cos\phi\sin\phi\ (W^2 - L^2) & \\
A_4 = & W^2L^2 & \qquad \text{(B-5)} \\
B_1 = & -2T^2(X1W^2\cos\phi - Y1L^2\sin\phi) & \\
B_2 = & -2T^2(X1W^2\sin\phi + Y1L^2\cos\phi) & \\
B_3 = & -2Z1L^2W^2 & \\
B_4 = & 2T^2(W^2\cos^2\phi + L^2\sin^2\phi) & = 2A_1 \\
B_5 = & 2T^2\cos\phi\sin\phi(W^2 - L^2) & = A_3 \\
B_6 = & 2T^2\cos\phi\sin\phi(W^2 - L2) & = A_3 \\
B_7 = & 2T^2(W^2\sin^2\phi + L^2\cos^2\phi) & = 2A2 \\
B_8 = & 2W^2L^2 & = 2A4 \\
C_1 = & T^2(W^2\cos^2\phi + L^2\sin^2\phi) & = A_1 \\
C_2 = & T^2(W^2\sin^2\phi + L^2\cos^2\phi) & = A_2 \\
C_3 = & W^2L^2 & = A_4 \\
C_4 = & 2T^2\cos\phi\sin\phi(W^2 - L^2) & = A_3 \\
C_5 = & -2T^2(X1W^2\cos\phi - Y1L^2\sin\phi) & = B1 \\
C_6 = & -2T^2(X1W^2\sin\phi + Y1L^2\cos\phi & = B2 \\
C_7 = & -2Z1W^2L^2 & = B3 \\
C_8 = & T^2W^2\ (X1 - L)\ (X1 + L) + L^2(T^2Y1^2 + W^2Z1^2) & \qquad \text{(B-7)}
\end{array}$$

Now let equation (B-3) be represented by:

$$At^2 + Bt + C = 0 \qquad \text{(B-8)}$$

This quadratic equation yields itself very quickly to analysis.

If:

$$B^2 - 4AC \leq 0 \qquad \text{(B-9)}$$

then the roots of equation (B-8) are complex (≤ 0) or double ($= 0$) and both are counted as nonintersections. If equation (B-9) does not hold, then the intersections are given by:

$$I_1 = \frac{-B + \sqrt{B^2 - 4AC}}{2A},$$

$$I_2 = \frac{-B - \sqrt{B^2 - 4AC}}{2A},$$

I_1 and I_2 can now be analyzed to determine if they lie in the "cloud" region of the rotated ellipsoidal cylinder or the rotated truncated ellipsoid. For the rotated ellipsoidal cylinder the points of intersection must satisfy:

$$(Z1 \leq I_1 \leq Z1 + T) \text{ and } (Z1 \leq I^2 \leq Z1 + T)$$

or

$$(I_1 \leq Z1) \text{ and } (I_2 \geq Z1 + T)$$

For the rotated truncated ellipsoid the points of intersection must satsify:

$$(I_1 \geq Z1) \text{ and } (I_2 \geq Z1)$$

APPENDIX C

SCENARIOS

The CLOUDS computer program has two models to internally generate the scenarios. These models are known as the direct intercept model and the chase model. A development of the direct intercept model can be found on page 16 of Reference 3. What follows here is a predictor-corrector solution of the chase model. See Section II.B.1 for a description of the chase model.

Given:

(1) Z height of B, HT

(2) Azimuth of B with respect to the X-axis Θ_B

(3) Azimuth of A with respect to B's line of flight, Θ_A

(4) Inclination of A (at t = 0) with respect to the Z = HT plane, γ

(5) The line of sight distance between A and B at t = 0, DAB, (Figure C-1).

(6) Speed of A and B, V_A and V_B respectively

(7) Time increment between position calculations, DELT.

The problem is to find the path of A so that the tangent to A's path is always intersects B.

To solve this problem an iterative predictor-corrector scheme was used. The steps of the scheme are as follows:

(1) Find the initial positions

$$XA_o = DAB*\cos\gamma\cos\alpha$$

$$YA_o = DAB*\cos\gamma\sin\alpha$$

$$ZA_o = DAB*\sin\gamma + HT$$

$$XB_o = 0.0$$

$$YB_o = 0.0$$

$$ZB_o = HT$$

where

$$\alpha = \Theta_A + \Theta_B$$

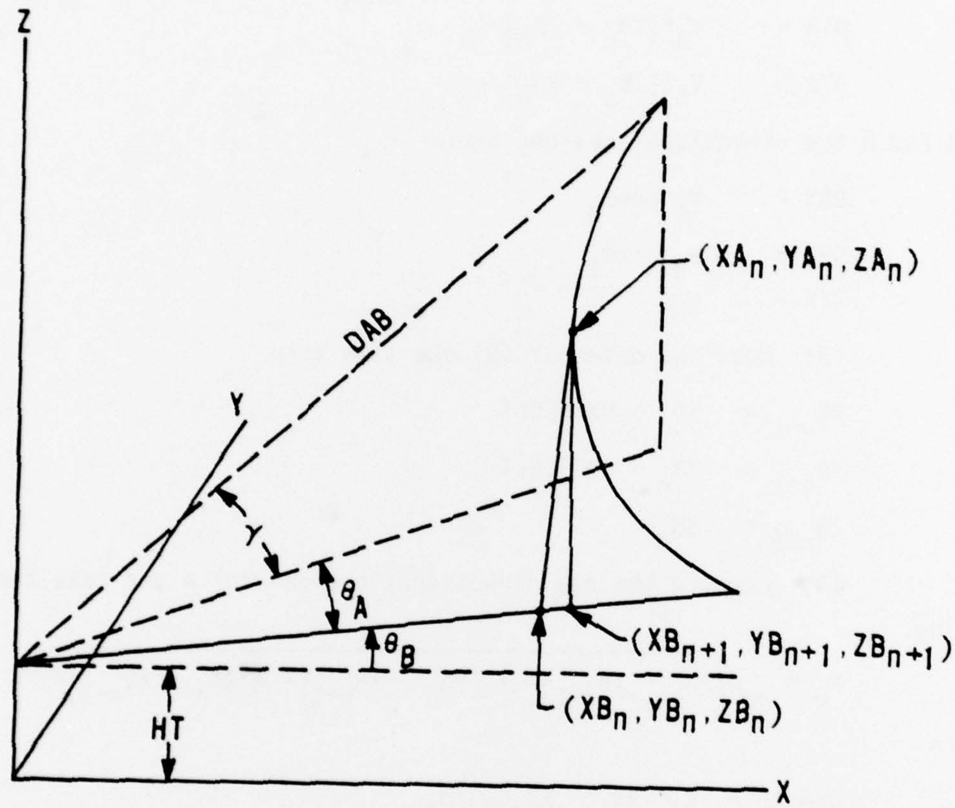


Figure C-1. Chase Model, the Aggressor, A, Heads Directly Towards the Defender, B, at All Times.

(2) Compute the directional cosines for the motion of both crafts, using:

$$\rho_o = \sqrt{\left(XA_o - XB_o\right)^2 + \left(YA_o - YB_o\right)^2 + \left(ZA_o - ZB_o\right)^2}$$

The directional cosines for A are:

$$DXA = V_A{*}\left(XB_o - XA_o\right)/\rho_o$$

$$DYA = V_A{*}\left(YB_o - YA_o\right)/\rho_o$$

$$DZA = V_A{*}\left(ZB_o - ZA_o\right)/\rho_o$$

and for B the directional cosines are:

$$DBX = V_B{*}\cos\theta_B$$

$$DYB = V_B{*}\sin\theta_B$$

$$DZB = 0.0$$

(3) Move the defender (B) one time step

$$XB_{n+1} = XB_n + DXB{*}DELT$$

$$YB_{n+1} = YB_n + DYB{*}DELT$$

$$ZB_{n+1} = ZB_n$$

(4) Compute the new directional cosines for A and take the average using:

$$P_n = \sqrt{\left(XA_n - XB_{n+1}\right)^2 + \left(YA_n - YB_{n+1}\right)^2 + \left(ZA_n - ZB_{n+1}\right)^2}$$

then

$$DXA_{new} = V_A{*}\left(XB_n - XB_{n+1}\right)/\rho_n$$

$$DYA_{new} = V_A{*}\left(YB_n - YB_{n+1}\right)/\rho_n$$

$$DZA_{new} = V_A{*}\left(ZB_n - ZB_{n+1}\right)/\rho_n$$

$$DXA = \left(DXA + DXA_{new}\right)/2.0$$

$$DYA = \left(DYA + DYA_{new}\right)/2.0$$

$$DZA = \left(DZA + DZA_{new}\right)/2.0$$

Where the "=" sign in the last three equations is a fortran "=" sign and is read DXA "becomes" . . . .

(5) Move the aggressor one time step

$$XA_{n+1} = XA_n + DXA*DELT$$

$$YA_{n+1} = YA_n + DYA*DELT$$

$$ZA_{n+1} = ZA_n + DZA*DELT$$

(6) Go back to 3 and repeat the process until the crafts are within 0.5 meter.

The accuracy to which the trajectory of A is calculated can be increased by iterating steps three through five 100 extra times (and thus a time increment of DELT/100 must be used) and storing every 100th position that is calculated.

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